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I - SYNOPSIS

This report covers an investigation on the Deforest Scratch Gage. The scratch gage has been studied with three objects in view; first to determine its application, second to determine its accuracy, and third to determine the technique of using the gage. The third requirement led to a study of the technique of using the microscope, since the scratch gage records only the actual strain in the material, and thus some means of enlarging the strains so that they could be studied was necessary. It was found that the scratch gage will record average vibratory and impact strains. However, it was also found that the scratch gage is not certain or dependable, since only about one test in two gave a good clear scratch which could be studied without any interference. In a tension calibration test made with the gage, fastened to a one-inch square bar, the stress given by the scratch gage checked the actual stress within one per cent. However, for ordinary use it is not thought that the gage will give stresses much closer than one thousand to two thousand pounds per square inch in steel, since in many cases the width of the scratch is equivalent to a stress of one thousand pounds per square inch. The strains were measured by a filar micrometer, and by taking pictures of the scratch under the microscope and scaling the strains on the print. The accuracy here was limited by the magnification, and the accuracy of the microscope. Thus, the gage is not too accurate for quantitative use in steel unless the stresses are high. However, for materials with low modulae of elasticity, it may give good results. About the smallest strain which can be measured is 0.0001-in. in a two-inch gage length.

II - DESCRIPTION OF THE GAGE

A sketch of the gage is given in Fig. 1. The gage is in two parts; one, the target, the other, the scratch arm carrying a special abrasive held under spring contact with the polished chrome plate recording surface. The particular feature of the gage is the method of causing the scratch arm to progress over the target at right angles to the direction of the strain record. In this case, a drive is obtained by using the difference between the coefficients of static and moving friction. Between the clip bar on the target, "a" in Fig. 1, and the spring arm "b" is a generous amount of friction. The gage is fastened in place on the surface to be strained with the arm in the center of its travel. The arm is then moved over to one side or the other of the target, bending the spring fulcrum "c". The friction is sufficient to prevent the return of the arm to the center under static conditions, but when the distance between the gage points "g" and "e" is changed, the transverse force due to spring "c" causes arm "b" to move slightly toward the center with each longitudinal slip of the arm under slip bar "a". It is always assumed that there is power available for the deformation to be measured, and that the friction between target and scratch arm does not change the system to which the gage is attached.

transverse
The traverse motion of the scratch arm is regulated by the stiffness of the spring and the friction. The latter can be widely varied by bending bar "a" to a higher or lower level as compared with the level of the target. If a large number of stress variations are to be recorded, and the motion is a simple one in which harmonics are of no interest, the friction can be high, and the traverse small, and a close packed record will result. On the other hand, if the details of the small deformations are desired, the friction can be reduced and a picture will result in which fewer vibrations are recorded, but more detail is shown.

III - OPERATION OF GAGE

When the target is purchased, it is protected by a piece of paper pasted to the face. The arm is inserted through the slot of the target, and then the target and arm are fastened to the specimen on which the strains are desired. The gage may be screwed, clamped, or soldered to the specimen, and in the tests made in the laboratory, Duco cement was found very effective and convenient for this purpose. Since the gage is very light, weighing but two grams, it does not take much fastening and can also be easily fastened to rapidly moving pieces.

When ready to make a record, peel the protecting paper from the target, and traverse the scratch arm to the end of its travel in either direction. This draws the zero or base line on the target, and this is usually visible to the naked eye, and can be easily seen with a reading glass. Two records can be made on each target, one starting at each end. However, if the runs are short, several of them can be made on the same side of the target by moving the arm very slightly by hand, after each small run.

To remove the target, move arm to the center, unclamp, bend target sharply between friction bar and record surface to remove arm without damage to abrasive.

After carefully removing the arm, wash the target with alcohol to remove the traces of the rubber compound left by the protecting paper. The target probably cannot be used again, but the arms may be used for an indefinite number of observations.

IV - EXAMINATION OF STRAIN

Examine target at a fairly low magnification of forty to one hundred times. This preliminary examination will usually show if any suitable strains have been recorded. The record, if any, will be in the form of a series of scratches on the chromium plated target. Since a number of individual grit particles are imbedded in a suitable matrix of cured rubber, the number and position of the scratching points will be somewhat haphazard, but several types of scratches may be recorded. Some will be too deep and ragged for good measurement, some will be too faint and some will be satisfactory. A satisfactory scratch is one which is fine, and yet readable, and which has a good zero line. If the zero line is too faint one may be able to use the zero line of another scratch; otherwise the strains measured will give only the maximum variation of the stress but not the actual values.

Fig. 2 shows a picture of some strains magnified forty-eight times. There are a number of records formed by the grit particles, but as can be easily seen a number of them interfere with each other and the scratches from some of the others are too deep and jagged. However, one fine line near the center of the photograph offers possibilities.

The target is then clamped so that this scratch is in the center of the microscope field as shown by the cross-hairs in the microscope. The objective is then carefully removed so that the target will not be disturbed, and Fig. 3 illustrates what was seen when the picture was enlarged 210 diameters. The bottom scratch is too irregular to obtain any accuracy. However, the top scratch offers possibilities. It could be just barely seen in Fig. 2, and so the target is adjusted to bring it to the center, the objectives are changed for higher power, and Fig. 4 gives us the final picture at a magnification of 430 diameters. Normally, in an ordinary test, the last picture would be the only one taken.

The initial zero line can be easily seen. The difference between the two parallel lines is the static stress, the maximum amplitude of the vibration gives the impact stress. These can be easily scaled off with a pair of ordinary dividers. The distances are found to be 2.54 and 0.55 in. which gives an impact factor of 4.62. Actually, this factor is somewhat modified in the actual test, since part of the load which gave the static stress did not act with the impact load. The actual impact factor was 6.5.

The strains were photographed by means of the metallographic microscope in the laboratory. This microscope is equipped with a camera which fits into the eyepiece and takes pictures nine by twelve centimeters. The image on the ground glass has the same magnification as that seen by the eye when a ten-diameter eyepiece is used. The strains can be observed through an eyepiece attachment on the camera or by observing the picture directly on the ground glass. The best pictures were obtained by using panatomic film which is sensitive to red light. The plates are exposed from four to six seconds with about maximum illumination in the field.

The microscope was calibrated, with the eyepiece set on the 170 mm. mark and using a micrometer stage graduated to 0.01 mm. The following are the magnifications obtained with this eyepiece setting and the following objectives; No.1b gives 46.5x, No.4 gives 210x, and the No.6 objective gives a magnification of 481x. These values may vary depending on how the microscope is focussed, and variations of plus or minus two per cent were noticed. It is felt that this is about the extreme range. These values differ considerably also from the constants furnished with the microscope.

The microscope has also been calibrated using a filar micrometer eyepiece. Eyepiece No.1506 which is usually kept in the structural models laboratory was used. It was found that a reading of one on the eyepiece was equal to 69.20×10^{-6}

inches with the 1b objective, 16.59×10^{-6} inches with the No.4 objective, and 7.96×10^{-6} inches with the No.6 objective. Thus a little more accuracy is obtained with this method than by the use of the camera. However, this is offset by the fact that the photograph gives a permanent record to which one can always refer. In addition, the field of view is, of course, extremely limited with the larger objectives and if the target is disturbed while using the filar micrometer, one can spend quite a bit of time before the object is again lined up in the field of view.

V - CONCLUSIONS

a. The scratch gage may be used to measure impact and vibratory strains.

b. The gage cannot always be depended upon to give a reading. If at all possible, it is suggested that two or more gages should be used at the location where the strains are desired.

c. The gages will usually give strains within two to three per cent. The microphotographs may have errors of the same order of magnitude. The resultant error of an observation should not be much over five per cent.

d. Strains can be measured as small as 0.00005-in. per inch. For steel this is equal to a stress of 1500 lb per sq in., and for materials with lower values for the modulus of elasticity, the minimum stress is correspondingly smaller.

APPENDIX

A. DESCRIPTION OF MICROSCOPE

Since the microscope is such an important instrument in using the records of the scratch gage, a brief appendix on the microscope has been added to the report.

A microscope consists essentially of an eyepiece, a draw tube, an objective, and some means of providing enough illumination to see the enlarged image. Both the objective and eyepiece have an initial magnification, and the total magnification depends on the tube length. With the proper tube length, the total magnification equals the product of the objective and eyepiece. The standard tube length is 160 mm. which gives an image at a distance of 250 mm. from the eye.

Both the objective and eyepiece consist of several lenses, and each lens as a rule consists of various types of glass cemented together to try to compensate for the optical errors inherent in a simple lens. The most common errors are Chromatic and Spherical Aberration.

Chromatic Abberation causes indistinct images in the microscope since the lights of different wave lengths focus at varying distances from the lens. Thus white light which consists of all the colors will give a number of images of different colors. A sketch showing this is given in Fig. 5. Achromatic lens corrects this condition somewhat but apochromatic lens provides the most correction.

Spherical Aberration occurs when light is passed through a lens, because the portion of light passing through the outermost edges is refracted to a greater degree than that at the center. Apochromatic lens provide the best correction also for this condition.

An objective has five important properties; magnifying power mentioned above, numerical aperature, resolving power, depth of focus, and flatness of field.

The numerical aperature may be defined as the light gathering power of the objective. The purpose of all objectives is to receive and combine into an image a larger solid cone of light from the object than can normally be received by the unaided eye. The clearness of detail depends largely upon the numerical value of this angle of light, i.e., the angular aperature. Angular aperature refers to the solid apex angle of the cone of light whose apex lies at the object or at the point of the object which transmits or reflects light. The base of the light cone corresponds to the light opening of the system of lenses formed by the objective mounting.

The number of light rays admitted into the objective depends not only upon the angular aperature but also on the index of refraction of the medium between the object and the front lens of the objective, since a dense medium will bend the light rays from the object so they pass into the objective.

The numerical aperature N.A. thus equal n sin u where n is the index of refraction, and u is half the cone angle. This is illustrated in Fig. 7. This shows why better results can be obtained with oil immersion. Since the index of refraction of oil is greater than 1, more light is reflected through the lens.

The resolving power is the ability of the objective to produce sharply defined images. It depends on the numerical aperature and wave length of light used to illuminate the object. If a very narrow central pencil of light is passed into the objective, the finest detail which can be shown with sufficient eyepiece magnification will equal $\frac{\lambda}{N.A.}$ where λ equals the wave length of the light used and N.A. equals the numerical aperature of the objective. If, however, this narrow pencil of light is increased in diameter or the original narrow light beam is made oblique, so that in either case the pencil of light completely fills the objective, the resolving power will be at a maximum and its numerical value increased by two. This principle is applied by opening the iris diaphragm of the illuminating source or by decentering it.

For example, if an objective of numerical aperture of 1.00 and an initial magnification of 100x is used with green light (λ = 0.00053 mm) under conditions of illumination such that the resolving power = $\frac{\lambda}{2 \text{ N.A.}}$ then the maximum resolution which can be obtained is equivalent to lines spaced $\frac{0.00053}{2 \times 1}$ of 0.000265 mm. apart. With proper eyepiece magnification, these lines will appear as distinct and separate images. Lines which are spaced closer together cannot be distinguished seen, regardless of magnification.

The human eye at a distance of 10 in. from the object can resolve lines which are spaced 0.11 mm. apart. Therefore in order to see lines originally spaced at 0.000265 mm., and magnified 100x by the objective, the magnification required by the eyepiece must be $\frac{0.11}{(0.000265)(100)}$ = 4x and the total magnification equals 400x.

The depth of focus is the ability of the objective to produce a sharply focussed image of the entire field of view. This is of importance where the surface is irregular. This property is inversely proportional to the numerical aperature and cannot be changed by any known methods of correction.

The flatness of field is due to the inherent curvature of field. This causes the center portion to be out of focus as compared to the rim. Objectives with high numerical aperature have a decided lack of flatness of field.

The eyepiece magnifies the image formed by the objective; they may be of many types.

In the usual metallurgical microscope the object is illuminated by reflected light.

B. ADJUSTMENTS OF MICROSCOPE

In the laboratory microscope, there are the usual coarse and fine adjustments to focus the object, and to bring the table into focus. The eyepiece should be set to the proper tube length which is 170 mm.

The illumination is provided by a small eight-volt bulb.

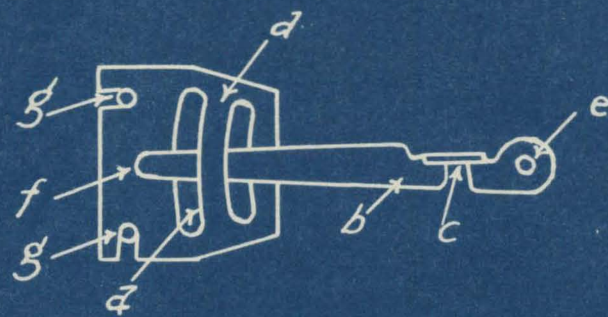
The first adjustment is the aperture diaphragm. It controls the pencil of light entering the microscope and thus increases the N.A. of the objective. Theoretically, the maximum resolving power occurs when the pencil of light is adjusted so as to just fill the bottom lens. Actually, it should only fill about two-thirds since bad effects due to aberration occur above this point.

The second adjustment is the field of view diaphragm. It minimizes glare, and light reflection within the tube. It is so focussed by means of a lens so that its image is focussed into the plane of the specimen surface. This adjustment is immediately in front of the field of view diaphragm on the laboratory microscope. As the diaphragm is closed, the field becomes smaller with increasing contrast between structural constituents. It should be closed to a point where only the portion of the field being examined can be seen.

The vertical illuminator is of the bright field type. That is the image appears dark on a light field. The light rays go through the objective twice as shown in Fig. 8. The light is reflected down from the prism as shown in the figure, goes through the objective, and is reflected back through the objective to the eyepiece. The prism reflector cuts down the N.A. one-half in one direction since it takes room in the telescope. The prism gives no light losses, and so greater contrast and more brilliant images are obtained.

To check the position of the prism, stop down the aperature as much as it will go, and note the reflection on the polished specimen. The aperature hole should show as in Fig. 9. The telescope is equipped with a Plane Glass Reflector which completely fills the tube as shown in Fig. 10. This is put into use by pulling the knob which slides the prism out and the glass in. Neither the contrast or brilliancy are as great as when the prism is used since more light is reflected and lost in the side walls of the tube. However, the resolution is improved.

Oblique illumination is used when there is little or no contrast. It enhances contrast since irregularities cast shadows under this lighting. It will also increase the N.A. as mentioned before. Oblique illumination may be obtained by closing the aperture, diaphragm and then decentering it with respect to the normal optic axis, or by rotating the prism through a small angle.



DeForest Scratch Recording Strain Gage

FIG. 1

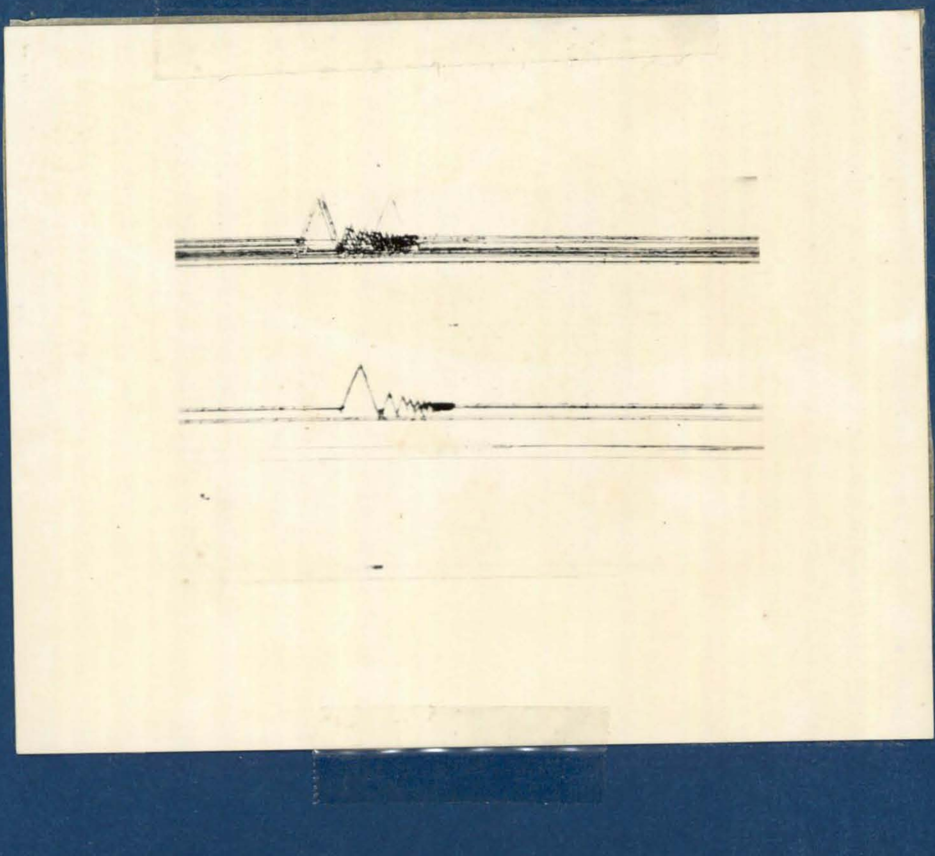


FIG. 2.

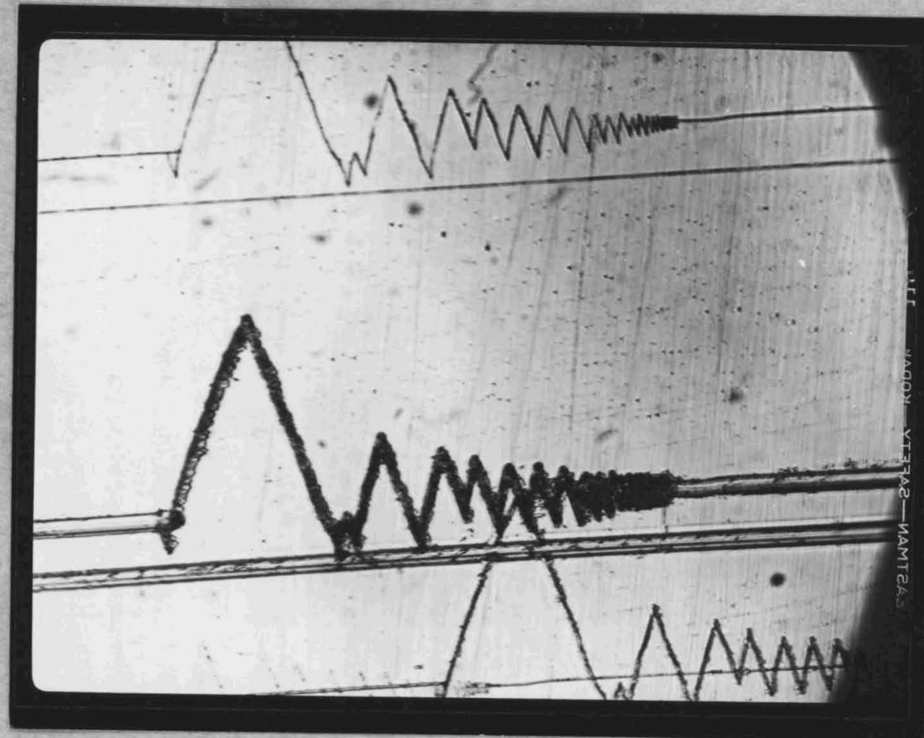


Fig. 3

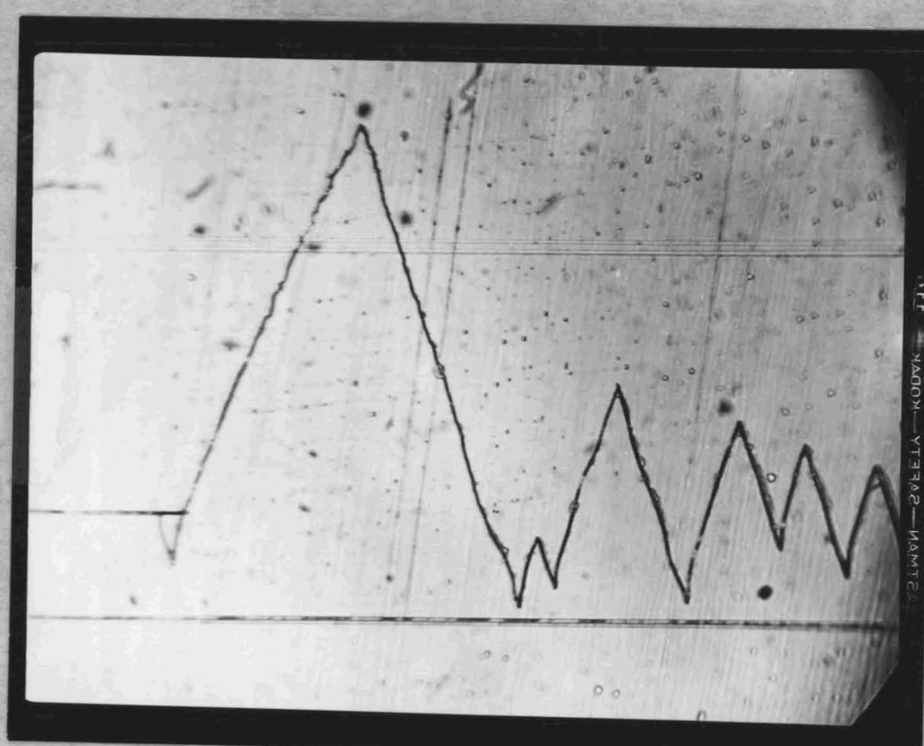


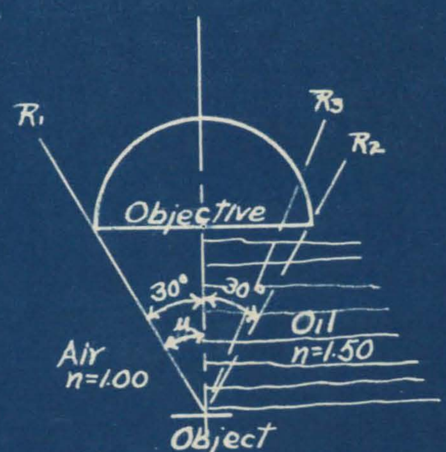
Fig. 4

Chromatic Aberration

Fig. 5

Spherical Aberration

Fig. 6



N.A. = $n \sin u$

Fig. 7

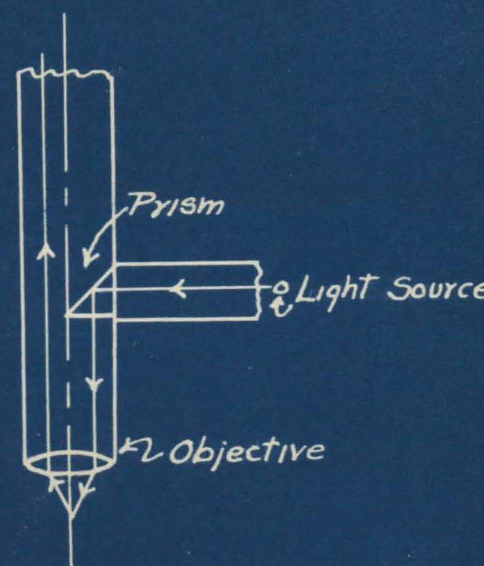


Fig. 8

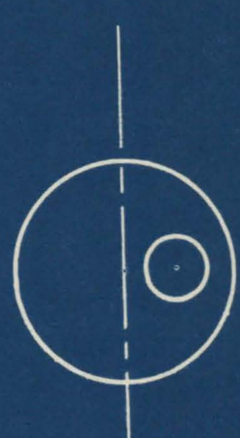


Fig. 9

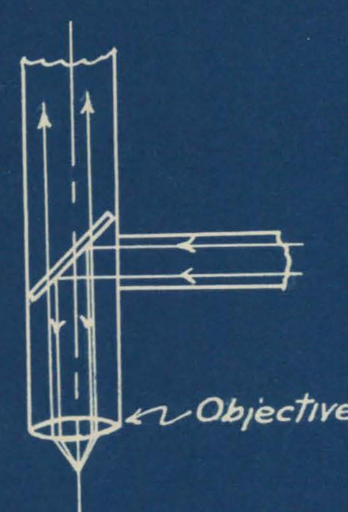


Fig. 10